HIGHWAY RESEARCH REPORT

LABORATORY INVESTIGATION OF GROUT FOR PRESTRESSED, POST-TENSIONED STRUCTURES

INTERIM REPORT

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BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

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RESEARCH DEPARTMENT

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY
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DEPARTMENT OF PUBLIC WORKS
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Interim Report
M&R No. 635117-2
FHWA D03-12

Mr. Robert J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is an interim report titled:

LABORATORY INVESTIGATION OF GROUT
FOR PRESTRESSED, POST-TENSIONED STRUCTURES

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Under the Direction of

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Under the Supervision of

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Very truly yours,

JOHN L. BEATON
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Attachment

REFERENCE: Weaver, R. E., McCormick, J. L., Watkins, R. L., and Freeman, R. J., "Laboratory Investigation of Grout for Prestressed, Post-Tensioned Structures", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. 635117-2, FHWA No. D03-12, November 1971.

ABSTRACT: A study was made to determine the effects of various admixtures, cement brands, and air entrapment/entrainment on the quality of neat cement grout. The relationship between these parameters and compressive strength was also investigated.

A number of laboratory grout mixing experiments were performed.

Results are tabulated for comparison, and where applicable, statistical analyses performed. It was found that admixtures, in the quantity used for this study, in all cases, decreased compressive strengths and increased the bleeding of grout. Higher mixing speeds tended to result in slightly more air entrapment.

KEY WORDS: Grout, grouting, cement, prestressed concrete, post-tensioning, bridges, corrosion statistics.

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The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Federal Highway Administration.

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LABORATORY INVESTIGATION
OF GROUT FOR PRESTRESSED DUCTS

INTRODUCTION

The corrosion of high-strength, prestressing steels in concrete became of serious concern with the increased use of prestressed concrete coupled with the fact that the grouting of ducts was not trouble-free. If the ducts were not completely filled with grout, then some degree of corrosion of the steel could be anticipated.

The first step in this study was to evaluate field grouting procedures. The results of this work are reported in "Investigation of Field Prestress Grouting Procedures," M&R No. 635117-1. This report deals with the next step, the anatomy of a neat cement grout. That is, how varying internal parameters affect grout quality. This report then deals with an evaluation of admixtures, cement brands, air entrainment/entrapment, and water-cement ratio, and how variations of the parameters affect compressive strength, efflux times, bleeding, shrinkage, and air content of the grouting material.

A statistical method (regression analysis) is frequently used in this report as a method of determining relative effects of parameter variability.

OBJECTIVES

This study was initiated to establish a more effective control of corrosion of mild and high strength steel used in highway bridge concrete by insuring that the steel will be completely encased in neat cement grout.

This phase deals with (1) defining the properties of neat cement grout, (2) determining what constitutes a "good" grout, and (3) what the effects of admixtures, cement brands, air entrainment and water-cement ratio have on compressive strength, bleeding, shrinkage and overall grout quality.

SUMMARY AND CONCLUSIONS

1. Admixtures

Originally upwards of 10 admixtures were considered to be included in the admixture phase of this study. Screening tests based on established criteria eliminated all but two for one or more of the following reasons: High molecular sugar, excessive shrinkage, excessive amounts of chlorides, sulphates and/or aluminum.

After two test series investigating the use of expansive commercially used admixtures, it became apparent that the principal purpose of the admixture was to offset the shrinkage of the grout and to overcome the results of poor mixing equipment by increasing the fluidity of the grout. When the admixture was added to a batch late in the mixing period, the viscosity was decreased initially and increased more slowly during the 20 minutes of quiescence than a batch to which the admixture was added early in the mixing period. (Quiescence is defined as a period between the end of the mixing cycle and the beginning of the efflux time test, the grout remaining undisturbed.) Therefore, the influence of the admixture was contingent upon when during the mixing period that it was added to the grout mix. In both cases, the admixtures used decreased the compressive strength and increased the bleeding of the grout. This was apparently because they acted as a "set retarder" thereby allowing the bleeding process to continue over an extended period of time. The reduction in compressive strength is believed to be the result of voids in the grout which are created by the hydrogen gas evolved from the aluminum powder/cement reaction. All of the commercially available grouting admixtures containing aluminum powder that were tested, acted as a volume expanding, water reducing agent. However, some brands of cement used for grout would rapidly "stiffen" with time. Therefore, in these cases, an admixture was found to be of great benefit when compared to the alternative of adding more mixing water. (On the whole, it appears that the most beneficial grout admixture would be one that simply contained an expanding agent and not other additions that would affect the setting properties of the grout.) More recent tests performed on grout approved for use have resulted in a reduction of the allowable amount of admixture that can be added. Previously, 0.75% by weight was allowed; currently only 0.1% by weight is allowed. The reasons for this change were tests that showed compressive strengths were lowered and setting times were increased as a result of admixture amounts of over 0.1 to 0.2% by weight. Slight, if any, advantage seemed to result in facilitated pumpability. It is our current feeling that 0.1% by weight at least will not adversely affect grout quality. Basically, an admixture should be tested with the cement at the time of usage so as to reasonably determine any adverse effects of the admixture.

The use of admixtures in grouting materials should be tested with the cement under the job conditions for compressive strength, bleeding, shrinkage and pumpability (by the flow cone). Research to date has identified these criteria but quantitative values have not been established. Such an investigation is not recommended at this time.

2. Cement Brands

It was apparent from test results that a particular water-cement ratio cannot be specified without specifying the cement brand or some property of the cement brand. The best procedure for field control would be to specify a maximum water-cement ratio and a minimum flow time.

The results of the Blaine Test for fineness of cement did not provide a reliable trend. A better method for distinguishing cements might be the Wagner Test described in Test Method C-115-58 of ASTM, or some other way of determining particle size distribution. In this test method the particles are graded, but due to the variability of cements within a particular brand, the Wagner method may also be of little use.

It was apparent from this test series that a change in the cement brand had a noticeable effect on the properties of the grout and possibly, in some instances, the cement should be tested prior to its use in the field. It also should be noted that the introduction of an admixture into an initially undesirable cement could possibly produce a good grout. This was in the case where the cement would require an abnormal quantity of water and/or would rapidly set.

3. Grout - Air Entrainment/Entrapment

The batches mixed without an air-entraining agent contained more entrapped air when mixed at higher speed; however, the actual amount of entrapped air in all of these batches was less than 0.5% and could be assumed to have an insignificant effect on the other properties of grout. Of the batches mixed with an air-entraining agent, resulting in air contents of up to 12%, there was again a tendency for those batches mixed at higher speeds to contain more air. It was also evident that for any given air content, grout mixed at a higher speed so as to impart greater mixing energy had a lower initial viscosity, but also had a lower stiffening rate. A lower stiffening rate is a desirable property because it would make grouting time less critical.

For any given mixing speed, when the entrained and/or entrapped air was plotted against initial flow time, and also against the flow time after 20 minutes of quiescence, it was obvious that both viscosity and stiffening rate increased with air content. Increasing the air content from 0% to 10% caused the initial efflux time of grout mixed at 1200 RPM to increase from about 12 seconds to about 13 seconds, and for grout mixed at 600 RPM from about 12 seconds to about 15 seconds. The corresponding approximate increases in the efflux times after 20 minutes of quiescence were from 13 to 17 seconds and from 13 to 52 seconds. It can be concluded that the reductions in viscosity and stiffening rate which are caused by high-energy mixing are not the result of mechanical entrapment of air, and that the use of an air or gas entraining admixture is not likely to improve the pumpability of grout. It was also found that for admixture contents greater than 0.75% per sack of cement, the expansion of the grout tended to become excessive - depending upon the brand of cement.

4. Compressive Strength

In the compressive strength analysis it was concluded that, generally, the 14- and 28-day compressive strength tests in laboratory test procedures were not necessary and could be eliminated. It was found that the 1 and 7-day strengths would produce acceptable results for predicting a reasonably good grout quality. Only one cement brand was used in this test series. Although strength is of importance, it is believed that excessive bleeding or any other process which could cause massive voids along the steel is of primary importance.

It was also concluded that more samples, several different cement brands, and a wider variety of curing conditions would be necessary to firmly establish the shape of the compressive strength versus curing time curve if the curve was to be used for further research analysis. Such an investigation is not recommended at this time.

TEST RESULTS

A. Admixtures

1. Test Series I

The purpose of this test series was to determine if there was a measurable difference between grouts using two different commercially available grout admixtures sold for the same purpose.

Sixty-five batches of grout were mixed using water-cement ratios of 4.5, 4.75, and 5.0 gal./sack of cement, two brands of Type II cement, and two brands of admixture. The mixing time was 15 minutes, and the mixing speed was 550 $\pm$ 20 RPM.

The admixture was added two minutes prior to the end of the mixing period for seven batches and at the start of the mixing period for the remaining 58 batches. The percentage, by weight of cement, of admixture used for each of the water-cement ratios for each of the cement brands was 0.50, 0.75, and 1.00 percent. Corresponding to the water-cement ratios of the two cement brands, control batches were mixed. Twenty-eight of the 65 batches were control batches.

Phase II of the Laboratory Test Procedures[1] was followed using the Jiffy or quad epoxy blade and a 5-gallon bucket containing four 8-rod baffles. The compressive strength of the grout was measured after 14 days.

In Table 1, extreme values are listed for the two admixtures, both of which contain aluminum powder as an expanding agent, and two cements.

Testing before 1967 indicated that grout containing an aluminum powder admixture would be less viscous than a similar grout containing no admixture.

The values shown in Table 1 are the highest strength, the greatest bleeding, the least shrinkage or most expansion, and the shortest efflux time exhibited by any of the supposedly identical batches in a group. It has been observed that increasing leakage of bleeding water from the expansion sample has always resulted in decreasing amounts of expansion. It must be emphasized that the listed values are of little quantitative significance, but they are useful in some qualitative respects. However, their greatest value is in emphasizing the extreme variation that was found when it was believed that our mixing practices were supposedly "constant."

Table 1

Cement Brand	Water-Cement Gal./Sack	Admixture Brand % of Cement Wt.	No. of Batches	14-day Strength lbs./sq. in.	Max. Bleeding % by Volume	Δ Vol., %	Quiescent Time, Minutes: 0	5	10	15	20	30
							Time of Efflux, Seconds					
P	5.00	None	2	3930	2.4	-1.4	12.1	13.2	14.0	14.8	15.3	16.9
		A0.50	3	2650	1.9	+1.4	11.8	15.3	∞	∞	∞	∞
		C0.50	2	2540	2.9	-0.9	13.6	14.0	14.0	14.8	16.1	17.7
		A0.75	1	1920	2.9	+3.9	11.4	12.8	12.8	14.0	14.8	17.7
		C0.75	2	2740	3.3	+1.2	11.2	14.0	14.4	15.3	15.6	17.7
		A1.00	3	2770	6.2	+4.2	11.2	11.6	13.6	14.8	16.9	23.5
		C1.00	1	2270	4.8	+2.2	12.0	13.2	14.0	15.3	16.9	24.0
	4.75	None	2	4310	2.4	-1.5	13.5	14.4	16.1	17.7	18.5	22.0
		A0.50	2	2200	5.7	+0.2	10.8	11.6	12.0	13.2	14.0	15.6
		C0.50	1	3060	2.4	-0.4	14.8	16.8	17.2	20.2	22.0	26.3
		A0.75	1		2.9	+3.0	12.0	13.1	14.3	17.8	18.2	
		C0.75	1	2940	2.9	+1.4	12.3	16.5	19.0	20.2	22.0	24.4
		A1.00	2	2830	6.2	+5.4	11.6	14.0	21.1	41.0	78.0	∞
		C1.00	2	3470	2.9	+4.6	12.1	14.0	16.5	20.2	24.0	29.6
	4.50	None	18	5740	1.9	-1.2	17.3	17.9	18.1	22.0	24.4	27.2
		A0.50	1	2420	4.8	-1.5	12.0	12.8	14.0	14.5	15.6	23.4
		A1.00	1	1710	11.4	-0.2	10.4	10.8	10.8	12.8	13.2	15.2
C	5.00	None	4	4470	3.3	-1.0	15.3	16.1	18.1	20.2	23.0	28.2
		A1.00	3	4150	5.2	+6.7	13.2	14.9	17.3	18.1	21.0	26.4
		A1.00	1	3930	4.8	+5.4	14.5	17.3	20.6	20.6	25.0	31.0
	4.75	None	2	4300	1.9	-0.7	17.7	25.8	30.0	37.0	53.0	∞
		A1.00	1	3400	4.8	+8.7	16.5	23.0	46.0	∞	∞	∞
		C1.00	2	----		+4.1	16.0	∞	∞	∞	∞	∞
	4.50	A1.00	7	----	4.8	+15.4	15.6	15.7	17.3	18.5	20.6	25.4

It should be noted from the tabulated values shown on Table 1, that use of either admixture resulted in reduced compressive strength. Likewise, the batches with admixtures resulted in an increased bleeding with an increase in dosage. Plastic shrinkage was generally reduced by using a lower water-cement ratio, and as expected, the expansion depended upon the amount of admixtures used. It was observed that a grout which expanded greatly also shrank a great deal below the point of maximum volume. Thus, depending on the mechanics of the expansion in an actual duct, it is conceivable that an expanding grout could result in a larger void system after the final set than a grout which does not expand.

This test series also indicated that if the admixture was added late in the mixing period, the viscosity would be lower initially and would increase more slowly with quiescent time as compared to a similar grout to which the admixture was added early in the mixing period. Similar related experience has been observed in the behavior of concrete mixes.

The values for time of efflux generally indicated that addition of either of these admixtures early in the mixing period reduced the viscosity of the grout for the batches with low water-cement ratios. This advantage was lost to some extent after a period of quiescence.

In most cases where an admixture was used, it was added to the batch at the start of mixing. However, the values tabulated for cement Ca, 4.50 gal./sack of cement, with 1% admixture A, are the result of a series of seven batches in which the admixture was added to the batch two minutes before the end of a 15-minute mixing period. It was found that the viscosity of grout made with cement Ca was more stable when the admixture was added late in the mixing period. Therefore, in general, it would appear to be more beneficial to add the admixture toward the end of the mixing time.

The seven batches of grout containing cement Ca at 4.5 gal./sack of cement were originally mixed in an attempt to determine what pressure might be generated by an expanding grout in a well sealed duct. One sample, placed in a 2-inch diameter pipe 62 inches long and stored in a nearly vertical position, generated a pressure of 186 psi 8 hours after placement. The pressure dropped to 82 psi after 48 hours and fell further to a minimum of 58 psi, and after 8 days, remained near this level for about 6 more weeks. When the pipe was opened, it was discovered that a great deal of hydrogen gas had accumulated in the space above the grout. Also, the surface of the grout was observed to be approximately 1.75-inch below the level of the paraffin which had been poured originally on top of the grout to separate it from the water in the fittings and pressure gate. The expansion apparently did not prevent bleeding. This would indicate that the grout shrank about 2.8% from its level of maximum expansion in this confined condition. An unconfined expansion sample taken from the same batch shrank 3.7% from its maximum expansion of 15.4%. This behavior may be quite significant when comparing spiral ducts (which have some leakage) to solid ducts.

The pipe and hardened grout were sawed longitudinally into two pieces. The grout appeared to be reasonably dense with few voids larger than 0.01-inch.

2. Test Series II

In this test series, the combination of a Type II cement (Ca) which had been previously tested, and an admixture (C) which had been previously tested with another cement, were investigated.

Twenty-six batches of grout were mixed, of which 14 batches were made without admixture for control. Of the remaining twelve, six were made with 0.26% admixture by weight of cement (4 oz. per sack), three batches using 0.50% admixture, and three batches with 0.75%.

Three different mixing energy levels were used: (1) 1200 RPM for 10 minutes (approximately 120 watt-min/kg of grout), (2) 1200 RPM for 4 minutes (approximately 50 watt-min/kg), and (3) 600 RPM for 4 minutes (approximately 15 watt-min/kg). The water-cement ratio was varied between 4.5 and 5.0 gal./ sack.

Phase III of Laboratory Test Procedures[1] was followed using the three rod mixing blade and the three matching baffles in the specially designed 5-gallon bucket.

The compressive strength was measured after 7, 14, and 28 days of curing.

The water-cement ratio required to produce a grout having an initial efflux time of 11.0 seconds was reduced by increasing the dosage of admixture. Table 2 shows the variation in water demand for four different admixture-cement ratios and two different mixing energy levels. It was apparent from this data that the admixture was an effective water-reducing agent.

It is of interest that the 7200 psi at which the cement was compressed was equivalent to the pressure that would be exerted on the bottom sack of a stack of cement 15,000 sacks high. Therefore, lumpiness sometimes observed in sacked cement appears to be related to hydration or lack of use of an anti pack-set agent during manufacture rather than stacking of the sacks of cement. The cement used may have had an anti-pack setting agent interground with it, thus preventing the kind of packing sometimes observed in sacked cement.

C. Flexible and Rigid Metal Ducts

1. Test Procedure

Five 40-inch lengths of flexible metal conduit were cast in concrete simulating flexible duct embedded in a concrete structure. In addition, five 40-inch lengths of steel pipe of the same diameter were also fabricated simulating rigid, impervious ducts. One specimen from each of these groups was filled under 60 psi pressure with grout from each of five different batches. After curing for 7 days, each specimen was sawed into 6 equal sections and the differences in the hardened grout were observed.

2. Analysis

In general, there was little difference between the two types of ducts when they were filled with a nonexpanding grout. Expanding grout seemed to fill the flexible metal duct better than the solid pipe. In the flexible duct, the hardened grout was full of small voids caused by the evolved hydrogen gas, and the continuous void at the top of the duct was relatively small. In the solid pipe, the small gas voids did not form, and the continuous void at the top of the duct was larger. The reason for the discrepancy in the void system is believed to be the result of the physical characteristics of the ducts. In the flexible ducts, gas could leak through the lapped walls and escape into the concrete. In the solid duct, the gas could only accumulate at the top of the duct as a result of gravity, not being able to escape, preventing maximum expansion of the grout.

D. Effects of Temperature

1. Test Procedure

In the three following test series, Phase III of the Laboratory Test Procedures was followed with variations in the mixing speed, water-cement ratio, and batching temperatures.

In the first test series, the water-cement ratio was 4.75 gallons per sack of cement and the mixing speed was 1200 rpm. The mixing equipment was the specially designed 5-gallon bucket with four baffles and the quad epoxy blade.

In addition to its water-reducing characteristics, the admixture caused the grout to expand during its initial setting period. Table 4 shows the change in volume, in percent, of unconfined samples of grout during the 7-day period after mixing. The water cement ratio was varied so that each batch had an initial efflux time of 11.0 seconds. Data are shown for four different admixture-cement ratios and three different mixing energy levels.

Table 4

Net Volume Change During the First 7 Days, in Percent, for Unconfined Grout Samples Having an Initial Efflux Time of 11.0 Seconds

	Admixture % by Weight of Cement			
	0	0.267	0.500	0.750
Mixing Energy = 120 watt-min/kg	-1.1	+0.2	---	---
50 "	-1.5	-0.2	+2.7	+5.5
15 "	-1.7	-0.4	+2.4	+5.3

The admixture had a similar effect in reducing the amount of shrinkage in a confined sample of grout. Table 5 contains the volume changes, in percent, of grout placed in 2x4-inch cylinders and used later as compressive strength specimens.

Table 5

Volume Change During the First 24 Hours, In Percent, for Unconfined Grout Samples Having an Initial Efflux Time of 11.0 Seconds

	Admixture % by Weight of Cement			
	0	0.267	0.500	0.750
Mixing Energy = 120 watt-min/kg	-3.0	-2.8	---	---
50 "	-4.1	-3.4	-0.8	-0.3
15 "	-4.6	-3.8	-1.1	-0.6

One of the detrimental effects of the admixture was to increase bleeding of the grout. Table 6 indicates the extent of this effect for grout samples mixed to have an initial flow time of 11.0 seconds.

Table 6

Bleeding Water, in Percent by Volume, of Grout Samples Having an Initial Efflux Time of 11.0 Seconds

	Admixture % by Weight of Cement 0	0.267	0.500	0.750
Mixing Energy = 120 watt-min/kg	1.2	2.2	---	---
50 "	1.4	2.5	3.1	3.0
15 "	1.5	2.7	4.0	4.5

Table 7 contains the compressive strength data for grout whose initial efflux time was 11.0 seconds.

Table 7

Compressive Strengths in lb./sq.in., of 2x4-inch Cylinders of Grout Having an Initial Efflux Time of 11.0 Seconds

Curing Time Days	Mixing Energy Watt-min/kg	Admixture % by Weight of Cement 0	0.267	0.500	0.750
7	120	3500	2500	---	---
7	50	2800	2100	2600	3500
7	15	2500	2000	2000	3000
14	120	4200	3100	---	---
14	50	3700	2800	3200	4500
14	15	3400	2600	2800	3900
28	120	5200	---	---	---
28	50	4500	---	3700	4800
28	15	4100	---	3500	4400

In this series of tests, the admixture composition was not known except that it did contain about 2% of aluminum powder by weight, and it is suspected that it also contained a lignin type of water-reducer. As indicated on Table 7, the compressive strength of the grout decreases with a decrease in mixing energy. However, it should be noted that in order to maintain the efflux time of the grout at 11.0 seconds, a reduction in mixing energy also resulted in an increase in water-cement ratio. Also, within limits, an increase in admixture also resulted in a reduction of the water-cement ratio. Therefore, the benefits of increasing the amount of admixture must be balanced against grout bleeding, shrinkage, strength, etc.

B. <u>Cement Brands</u>

1. Test Procedure

Six different brands of cement were mixed using 4.75 gallons of water per sack with no admixture. An initial efflux time temperature of 68°F was maintained for all the cement brands. Phase II of the Laboratory Test Procedures[1] was used with the mixing speed set at 500 rpm and the mixing time 10 minutes. The mixing blade that was used in this test series was the quad-epoxy blade.

2. Test Results

From Table 8 it can be seen that the initial efflux times vary from 12.6 to 27.0 seconds. This demonstrates the wide variation of water and/or mixing energy demands by samples of different brands of cement used in these tests.

Table 8

Cement and Grout Test Data

Brand Cement	Blaine CM^2/gm	Shrinkage, % by Vol.	Bleeding, % by Vol.	28-day Comp.St. psi	Efflux Times (Secs.) at: Init.	20 min.	30 min.
Mo	3380	0.70	0.4	6322	27.0	66.0	95.0
Co	3160	0.99	0.4	7214	17.3	38.0	39.0
Vr	3460	1.23	0.9	7162	15.6	22.0	30.0
Ca	3430	1.11	0.9	7060	13.7	18.7	22.0
SC	3410	1.42	1.2	6500	12.9	18.2	21.3
Pe	3510	1.64	1.2	5515	12.6	15.3	17.0

It was noted that the least viscous grouts had the least increase in rate of stiffening. From Table 9 it can be seen that the increase in efflux time ranged from 33% to 250% for quiescent periods of 30 minutes. (The original test data from which the percentage increase in efflux time was calculated is shown in Table 8.)

Table 9

Brand Cement	% Increase in Efflux Time Between 0 and 30 Minute Quiescent Periods	% Increase in Shrinkage from Cement with Least Shrinkage	% Increase in Bleeding from Cement with Least Bleeding
Mo	251	0	0
Co	125	41	0
Vr	92	76	125
Ca	61	59	125
SC	65	102	200

It can also be seen that the bleeding and shrinkage both were greater for low viscosity grouts. Trends could be established for both the shrinkage and the bleeding, but it should be noted that these mixes contain no admixture.

The 28-day compressive strengths in Table 8 indicated a definite trend from low to high where low compressive strengths corresponded with the low viscosities.

It was noted in Table 8 that cements yielding the higher viscosity grouts generally had the larger specific surface when they were measured using the Blaine apparatus described in ASTM standard test method C204-55, but a trend could not be mathematically established.

C. Air Entrainment/Entrapment

1. Test Series 1

The purpose of this test series was to determine the amount of air entrapped by the mixing process.

Twenty-five batches of grout were mixed at various speeds with two different blades and mixers without any air-entraining agent. Although there was some variation in the air content of batches mixed with different cements, there was no detectable relationship between air content and the speed or configuration of the mixer, nor was there any relationship between air content and viscosity of the grout. The range of values was 0.1% to 0.7% entrapped air in the grout. The amount of entrapped air in the grout was determined by means of Calif. Test Method No. 504.

2. Test Series 2

The purpose of this test series was to determine to what extent high energy mixing entrapped air into the mix, and what effect

Table 10

Mixer Speed rpm	Batch Temp. °F	W/C Gal/sk.	Admixtures %	Admixtures Type	Admixtures Minutes Mixed	Air %	Initial Efflux Time, Sec.	20 Min. Efflux Time, Sec.
600	70	4.75	----	None	10	0.0	11.7	13.7
600	73	4.75	----	"	10	0.0	11.7	14.3
600	67	4.50	----	"	10	0.0	12.2	68+
1200	75	4.50	----	"	10	0.1	11.8	12.9
1200	69	4.50	----	"	10	0.1	11.8	15.7
1200	75	4.75	----	"	10	0.2	10.9	11.9
1200	74	4.50	----	"	10	0.2	11.6	13.1
1200	76	4.75	----	"	10	0.3	10.7	11.3
1200	72	4.75	----	"	10	0.3	11.0	11.9
600	74	4.50	----	"	10	0.4	12.9	16.8
1200	77	4.50	0.10	H	By Hand	0.6	12.3	13.6
1200	73	4.50	0.10	H	0.5	0.7	11.8	14.1
1200	73	4.50	0.04	P	10	0.8	11.8	12.7
600	73	4.50	0.10	P	2	0.8	12.8	15.4
600	74	4.50	0.10	H	2	1.2	12.6	15.5
600	71	4.50	1.00	H	2	4.9	12.4	15.8
600	72	4.50	0.50	H	10	7.5	14.8	
1200	73	4.50	0.50	H	10	8.5	12.9	20
600	74	4.50	1.00	H	10	8.5	18.2	40
1200	78	4.50	0.50	H	10	9.0	12.6	15.0
1200	73	4.50	1.00	H	10	9.5	15.4	36
600	74	4.50	1.00	H	10	10.0	15.0	52
1200	80	4.50	1.00	H	11	11.0	14.0	16.9
1200	74	4.50	1.00	H	2	12.0	12.6	14.3

Type II Cement
7/8" Rotor w/3-7" rods, 3 baffles w/9 rods
Initial efflux time is mean of 2 samples - 20 minute efflux time is single observation

entrapped and entrained air would have on the viscosity of the grout.

Phase III of the Laboratory Test Procedures[1] was followed.

The mixer consisted of a specially designed 5-gallon bucket and the 3-rod mixer blade and matching baffles.

Generally, mixing time and the configuration of the mixer (blade, baffles, etc.) were the same for all batches. Mixing energy was varied by using two blade speeds - 600 and 1200 rev./min. All cement came from the same lot. Most batches were mixed with a water-cement ratio of 4.5 gal./sack of cement and the water temperature was varied in an attempt to make the final temperature of all batches 74°F.

Initial efflux time was measured by the flow cone method, twice for each batch, and also after 20 minutes quiescence it was measured once for each batch. Air content was determined using the modified Washington pressure type air meter.

Twenty-four batches of grout were mixed and the air content and efflux time of each was measured.

Some difficulty was encountered in entrapping air in the grout. Based on experience with concrete, the two air entraining agents employed should have given large air contents when added in the amount of 0.1% by weight of cement. The air entraining agents were a vinsol resin type. However, no significant amount of air (more than 2%) was entrained by using less than 0.5% admixture. The maximum air content, 12%, was obtained by using 1% admixture, a rather large dosage.

Batch data and results are shown in Table 10. A plot of entrapped air vs. mixing speed for ten batches without any admixtures showed a trend that higher mixing speeds may entrap slightly more air than lower speeds, but that the amount of air physically entrapped at any speed was virtually insignificant (less than 0.5%).

A plot of entrained air vs. mixing speed for six batches mixed with 1% air-entraining agent also indicated that a higher air content could be expected in batches mixed at higher speed.

The most interesting results of this test series which were shown in a plot of entrained air vs. initial efflux time, was its tendency to increase with air content. This was contrary to the hypothesis that entrained or entrapped air would reduce the viscosity. This effect was more pronounced for batches mixed at 600 rpm than for those mixed at 1200 rpm. Although there was more scatter in the data of a plot of entrained air vs. efflux time after 20 minutes quiescence, the same tendency of viscosity to increase with the air content was noted. Under the conditions employed to entrain air in these mixes, the effect seems to have been the creation of a thixotropic mass.

D. Compressive Strength

An analysis was made that indicated 14- and 28-day compressive tests could be eliminated. (See Appendix.)

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APPENDIX

The necessity of reporting the 14-day and 28-day values was reviewed. It could be seen that the elimination of these values would be economically desirable and would significantly reduce the elapsed time required to complete a grout mixing test. Before making a purely arbitrary decision to eliminate these values from future test series, an examination of the accumulated test results was completed.

Procedure and Results

The results of 56 previously run test batches using only one cement brand, were available for this study. The water-cement ratio varied from 4.5 to 5.0 gal./sack. Nine cylinders had been fabricated from each batch. Three had been tested at 7 days, three at 14 days, and three at 28 days.

The first step was to examine the data in terms of means and variances. Results of these calculations are shown in the table below.

Grout Compressive Strength Data

Statistic	Cure Time		
	7 days	14 days	28 days
$\overline{X}$	4262 psi	5158 psi	6109 psi
S_1	390 "	513 "	685 "
C_1	9.1%	9.9%	11.2%
S_2	225 psi	296 psi	395 psi
C_2	5.3%	5.7%	6.5%

Where: $\overline{X}$ = mean compressive strength
S_1 = average standard deviation. This represents individual samples from the same batch
C_1 = coefficient of variation for S_1
S_2 = mean standard deviation. This represents the means of groups of three all sampled from the same batch
C_2 = coefficient of variation for S_2

Apparently the average variations within groups of three test cylinders increases with compressive strength.

Next, regression lines were calculated for curing time and average compressive strength using various transforms. The best fit

was found by plotting the log of curing time against compressive strength (semi-log) which is in accordance with results typically reported by others. Equation 1 is the regression equation:

$$S = 3068 \log_{10} T + 1660 \quad (1)$$

Where: S = compressive strength in psi
T = curing time in days
N = 168 averages of groups of 3, or 504 individual values

The standard error of the estimate was 633 psi and the mean 5176 psi. There were equal numbers of 7, 14, and 28-day cured specimens and the fit was almost as good using log-log transforms or no transforms at all.

Some further examinations of the data were attempted, but nothing significant was observed.